CYCLONE TYPES AT 500 MB[1]

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ABSTRACT

Examples of three types of 500-mb. cyclone development, distinguished by the location of the cyclogenesis relative to the zonal velocity profile at 500 mb., are shown. Differences in the mean motion of all three cyclone types are shown to be statistically significant.

1. INTRODUCTION

In the course of an investigation into the statistical characteristics of cyclones at the 500-mb. level (Duquet and Spar [1]) it was observed that these cyclones could be classified into three types with statistically significant differences between the types in terms of their mean daily motions.

The cyclone types were distinguished by their original locations relative to the large-scale 500-mb. circulation. It was found that the zonal velocity profile at 500 mb. over a sector of the hemisphere could be used to separate the cyclones into three types which form north of, in, or south of the zone of maximum westerlies. Examples of each cyclone type, as well as of some subtypes, are described below.

The zonal velocity profile interacts with the cyclone development in a manner that depends on the cyclone type. The high-latitude (type I) cyclones, which form north of the maximum westerlies, contribute to an increase in the maximum westerlies. The low-latitude (type III) cyclones, which form south of the maximum westerlies, tend to diminish the west wind maximum and may produce a secondary maximum in lower latitudes, south of the Low. Such a development may represent the beginning of an "index cycle" in the form of a latitudinal shift of the zonal circulation. The effect of the middle-latitude (type II) cyclones, which form in the belt of maximum westerlies where the meridional thermal gradient is also usually a maximum at 500 mb., is to reduce the west wind maximum initially. However, the subsequent development of the velocity profile depends on whether the cyclone migrates northward or southward across the westerlies.

2. CYCLONE TYPES

The type I cyclone forms in high latitudes well north of the belt of maximum westerlies. Often these cyclones begin their existence in the Arctic Low itself, where they may drift for days about the North Pole. In the case illustrated in figure 1 the Low apparently originated well north of latitude 80° N. The low center then moved southward, and at 0300 GMT on April 25, 1956, the time of the map shown at the top of figure 1, had already reached latitude 64° N., west of Hudson Bay. Subsequently, as shown on the 0300 GMT maps in figure 1 for the next three days, the cyclone recurved and moved eastward.

The graphs accompanying the maps of figure 1 show the mean geostrophic zonal velocity profiles at 500 mb. over a sector 80° of longitude wide centered on the meridian of the Low. The geostrophic wind speeds were computed for overlapping 10° increments of latitude. The latitude of the cyclone is shown by the blacked-in circle. (Dashed unblacked circles in the later figures are used to denote the latitude of the incipient cyclone.) The cyclone remained north of the maximum westerlies during its entire existence. As it drifted southward, the maximum westerlies shifted toward the latitude of the cyclone and strengthened, mainly due to the contribution of the strong westerlies south of the Low. Although all type I cyclones first appear north of the maximum westerlies, not all of them exhibit the behavior shown here. In some cases the Low "breaks through" the westerlies and ends its existence south of the west wind maximum.

The type II cyclone develops in the strongly baroclinic region at 500 mb. which Palmén [2] has referred to as the 500-mb. frontal zone. These cyclones are also associated with cyclone developments at sea level. In fact many of them develop out of occluding frontal wave cyclones. This frontal zone is also the zone of maximum westerly wind. Thus type II cyclones appear first in the belt of strongest westerlies.

The appearance of a type II cyclone in the maximum westerlies distorts the velocity profile, sometimes producing a secondary maximum south of the Low. After

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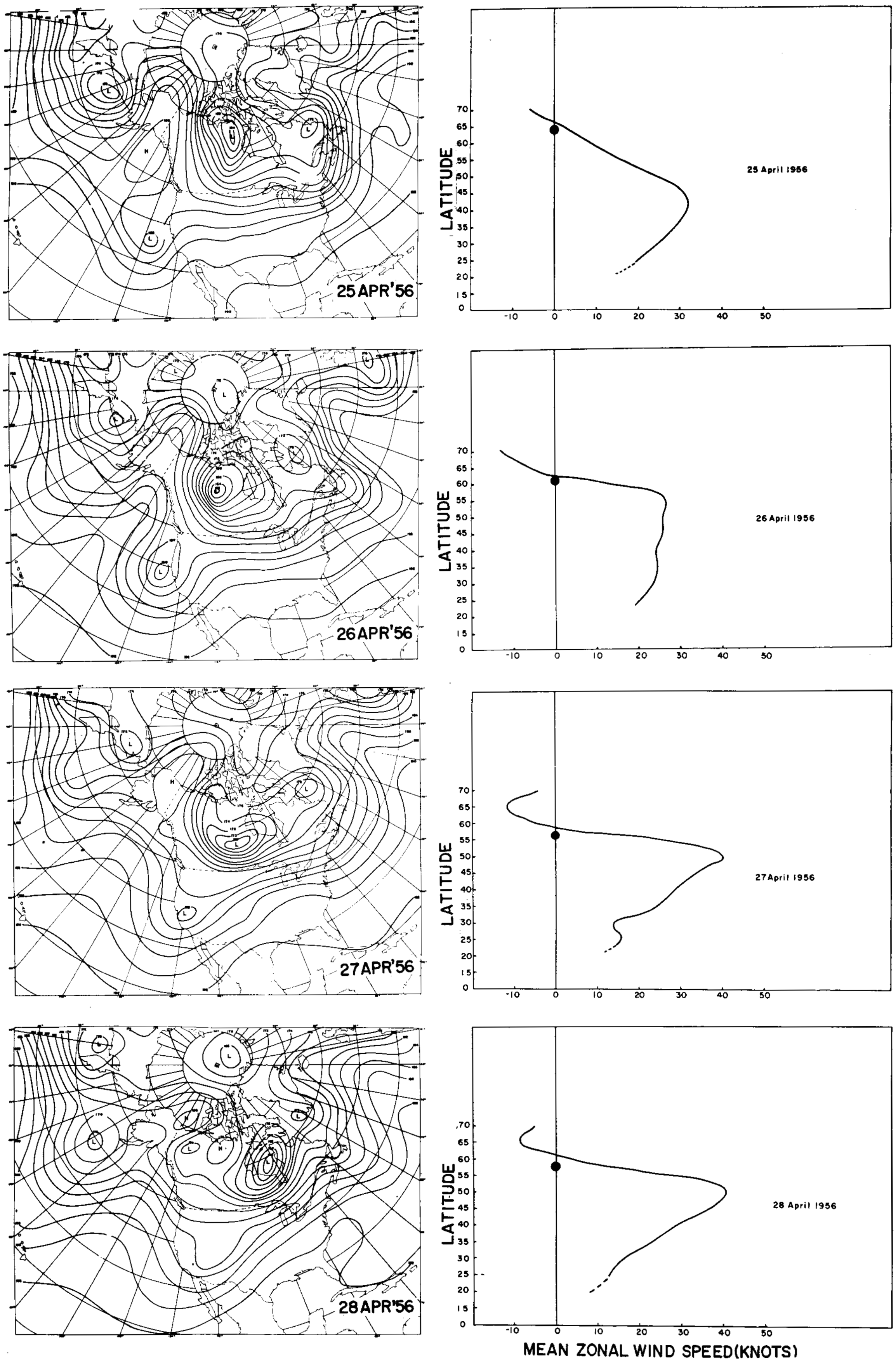

FIGURE 1.—Type I cyclone development at 500 mb., April 25–28, 1956. Geostrophic zonal velocity profiles on the right are computed for a sector 80° of longitude wide centered on the meridian of the cyclone. Black dot shows latitude of the cyclone.

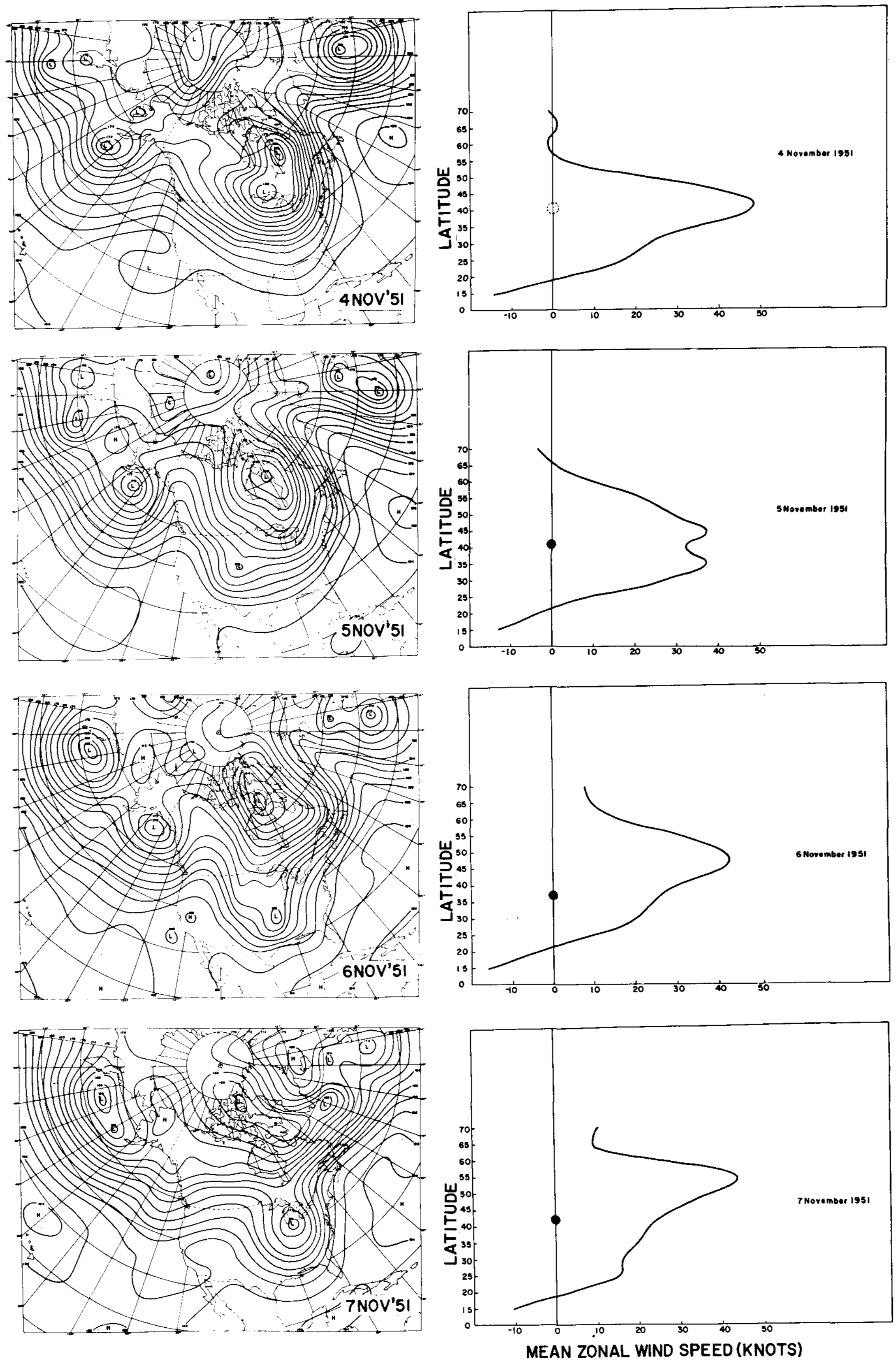

FIGURE 2.—Type II cyclone development at 500 mb., November 4–7, 1951. Dotted circle on velocity profile denotes latitude of incipient cyclone.

it forms, the Low almost invariably migrates across the westerlies further altering the velocity profile.

An example of a type II cyclone is shown in figure 2. As in figure 1, each of the 1500 GMT 500-mb. maps in the series is accompanied by a graph of the geostrophic zonal velocity profile in the 80-degree sector centered on the meridian of the cyclone. The series begins with the map of November 4, 1951 (at the top), showing the 500-mb. circulation prior to the formation of the Low. At this time the velocity profile exhibited a sharply peaked maximum of 48 knots near latitutde 40° N. With the formation of the cyclone over the western United States at latitude 41° N., the next day, the profile flattened and the maximum decreased to 37 knots. (A Colorado cyclone developed on the sea level map at this time.) Subsequently, as shown in the next two maps of the series, the low center moved southeastward to latitude 37° N., then recurved and traveled northeastward. During this period the strongest westerlies moved northward. By the end of the series, the cyclone, which had first moved southward away from the maximum westerlies, was migrating northward across the maximum westerlies.

The high speed of propagation of the cyclone shown in figure 2 is quite typical. Type II cyclones generally move with the velocity of the associated sea level Lows.

It should be mentioned that not all type II cyclones form in exactly the latitude of the maximum sectoral westerlies. In many cases the low center first appears a few degrees north of this latitude, but not so far north that it can be confused with type I.

Type III cyclones almost invariably evolve through an increase in the amplitude of a pre-existent trough in the westerlies. As the trough become elongated toward the equator, the strongest westerlies remain in the north while the cyclone forms in the southern part of the trough. The development of the cyclone frequently produces a secondary maximum in the velocity profile south of the Low. In the early stages these cyclones are rarely associated with sea level Lows. However, they may induce sea level cyclogenesis after they have developed.

The type III cyclones can be further sub-divided into four sub-types; IIIa, the cutoff Low; IIIb, the kona type Low; IIIc, the blocking type; and IIId, the pressure pulse type.

Since the cutoff Low (type IIIa) has been the subject of several detailed case studies, especially by Palmén (loc. cit.), the example shown here in figure 3, is included merely to show the formation of the cyclone in relation to the zonal velocity profile. The series of daily maps, beginning with that of 0300 GMT January 2, 1947, shows the appearance of the cyclone far to the south of the latitude of maximum westerlies over the central United States. After the formation of the cyclone, the velocity profile exhibits the characteristic secondary maximum south of the Low. However, this feature later disappeared, and the Low remained south of the strongest westerlies.

The kona (type IIIb) Low illustrated in figure 4 (March 7–10, 1950) has been described by Simpson [3] who used this local Polynesian term to designate a kind of sub-tropical cyclone which affects the Hawaiian Islands. The cyclone shown developed on March 9 in the trough west of Lower California. Kona type 500-mb. Lows are characterized by weak circulations. Unlike cutoff Lows, they are not the consequence of large-scale outbreaks of polar air. Although the core of the cyclone is relatively cold, the core temperature is very nearly the same as the latitudinal mean temperature. The low latitude at which these Lows form clearly distinguishes them from those described previously. But, like all type III Lows, they too develop in the southern end of a long-wave trough of increasing amplitude.

The blocking (type IIIc) cyclone begins with a meridional trough approaching a blocking-type ridge. The block is most persistent in high latitudes where a closed anticyclone is often found. The trough line rotates eastward until the southern end of the trough lies south of the anticyclone, and the cyclone then forms by a kind of fracturing of the trough. The high-latitude block remains, while the cyclone, far to the south, drifts eastward around it. A blocking-type cyclone formation over southern California is illustrated in figure 5 (May 17–20, 1956).

The designation, pressure pulse type (type IIId), has been used to describe those cases of trough amplification and cyclogenesis which appear to be induced by pressure pulses which travel around the periphery of the ridge to the west and enter the rear of the trough. These pulses appear on the 500-mb. maps as minor troughs, or, sometimes, only as a flattening of the ridge. On vorticity charts they appear as fast-moving, secondary, vorticity maxima. They are usually associated with pools or tongues of cold air at 500 mb. and with warm pools or tongues in the lower stratosphere. They can be seen most clearly in the 12-hourly height change fields at 500 mb. as traveling katallohypsal systems. When these systems overtake the trough they may produce retrogression, trough amplification, secondary trough development, or cyclogenesis.

An example of a pressure pulse type development on the Pacific coast is shown in figure 6. This development began on February 21, 1953, with a small-amplitude trough moving around the split ridge over the Gulf of Alaska. The disturbance is shown by the dashed 12-hourly isallohypses which are drawn for an interval of 100 geopotential feet on the four maps. Arrows show the path of the katallohypsal center (marked with an F). As the disturbance reached the coast on the 22d, the ridge behind it re-established itself over the Gulf of Alaska.

The cyclone formed over the Pacific coast within the next 24 hours as the katallohypsal center moved south-

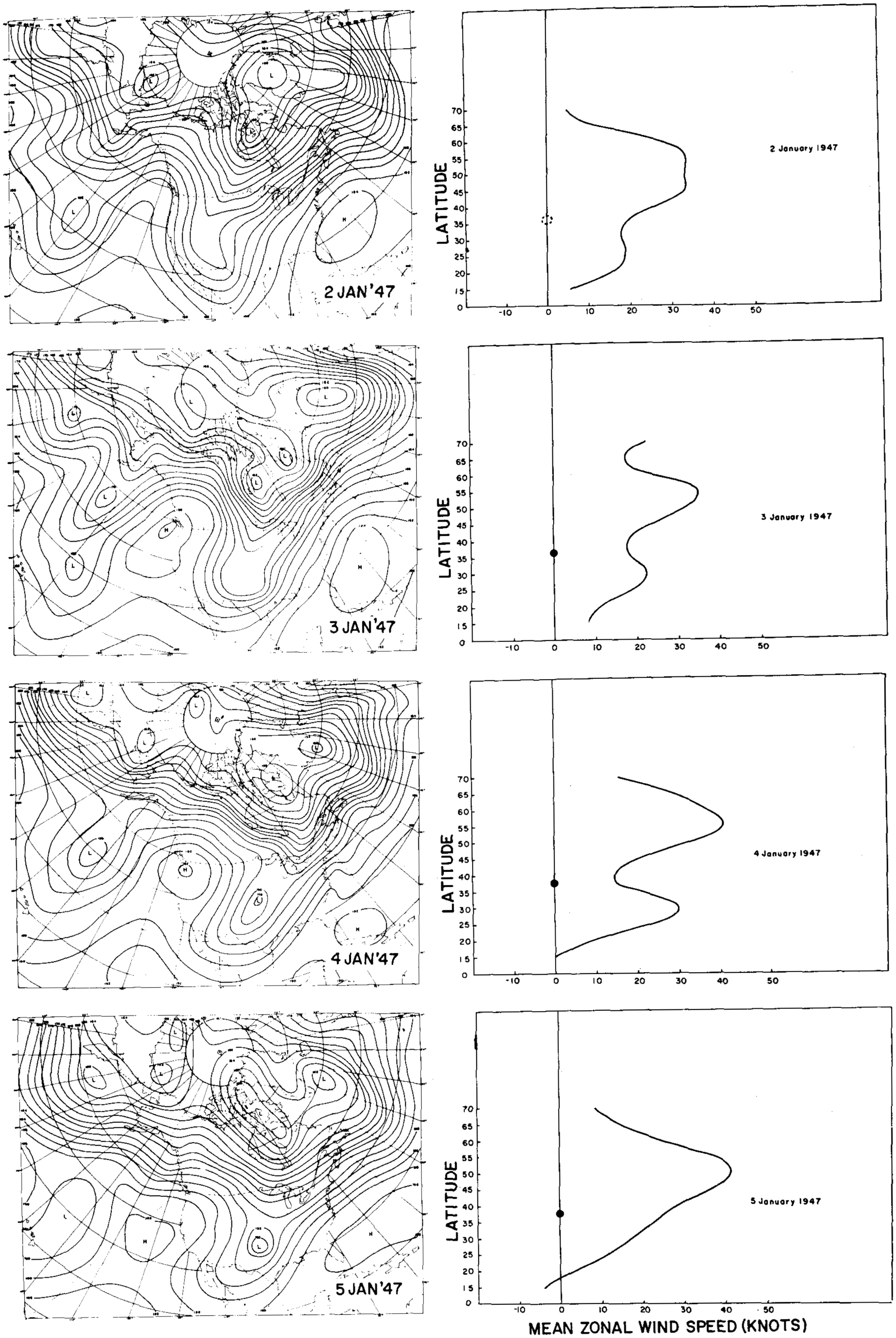

Figure 3.—Type IIIa (cutoff) cyclone development at 500 mb., January 2–5, 1947.

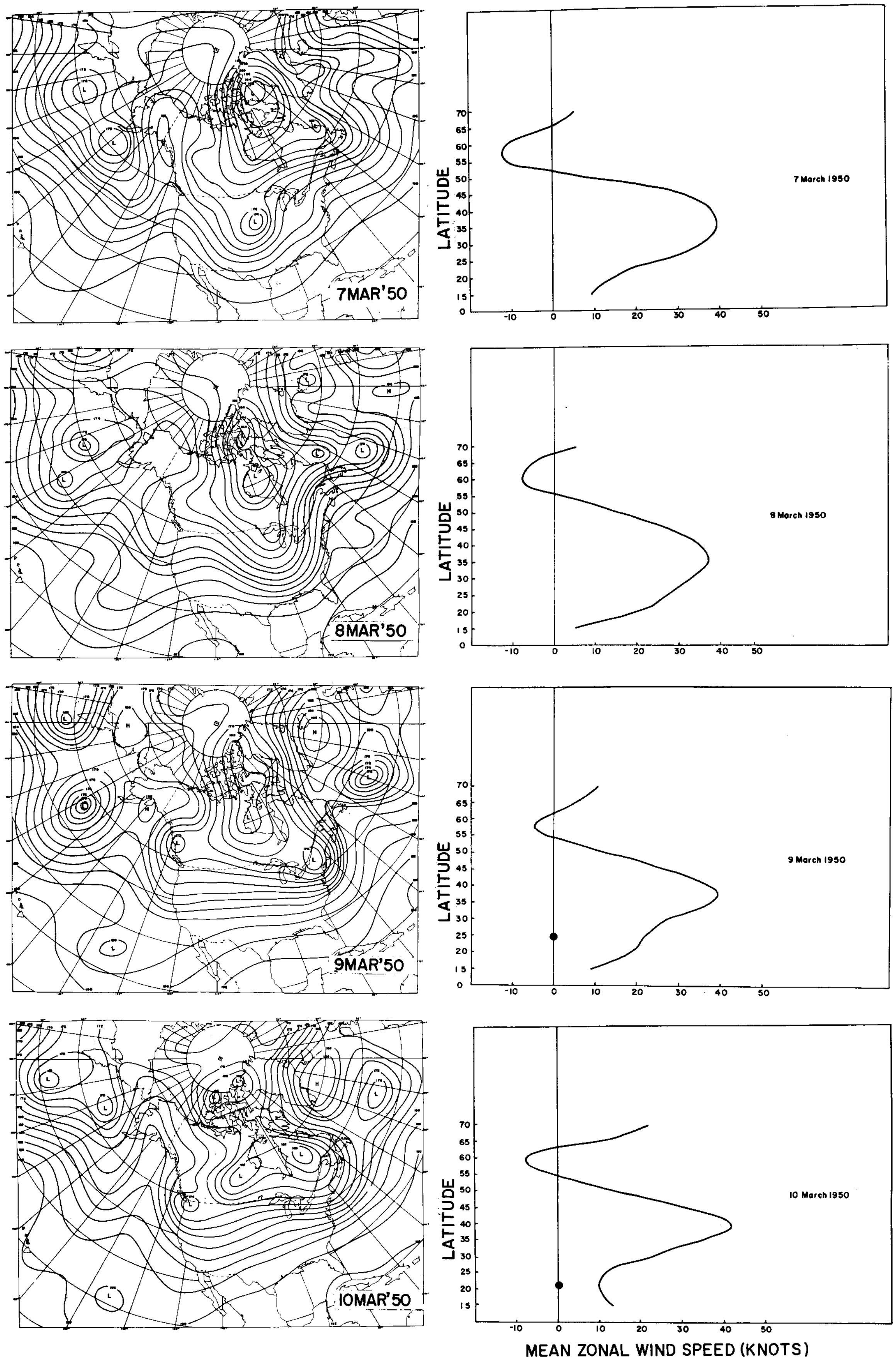

Figure 4.—Type IIIb (kona) cyclone development at 500 mb., March 7–10, 1950.

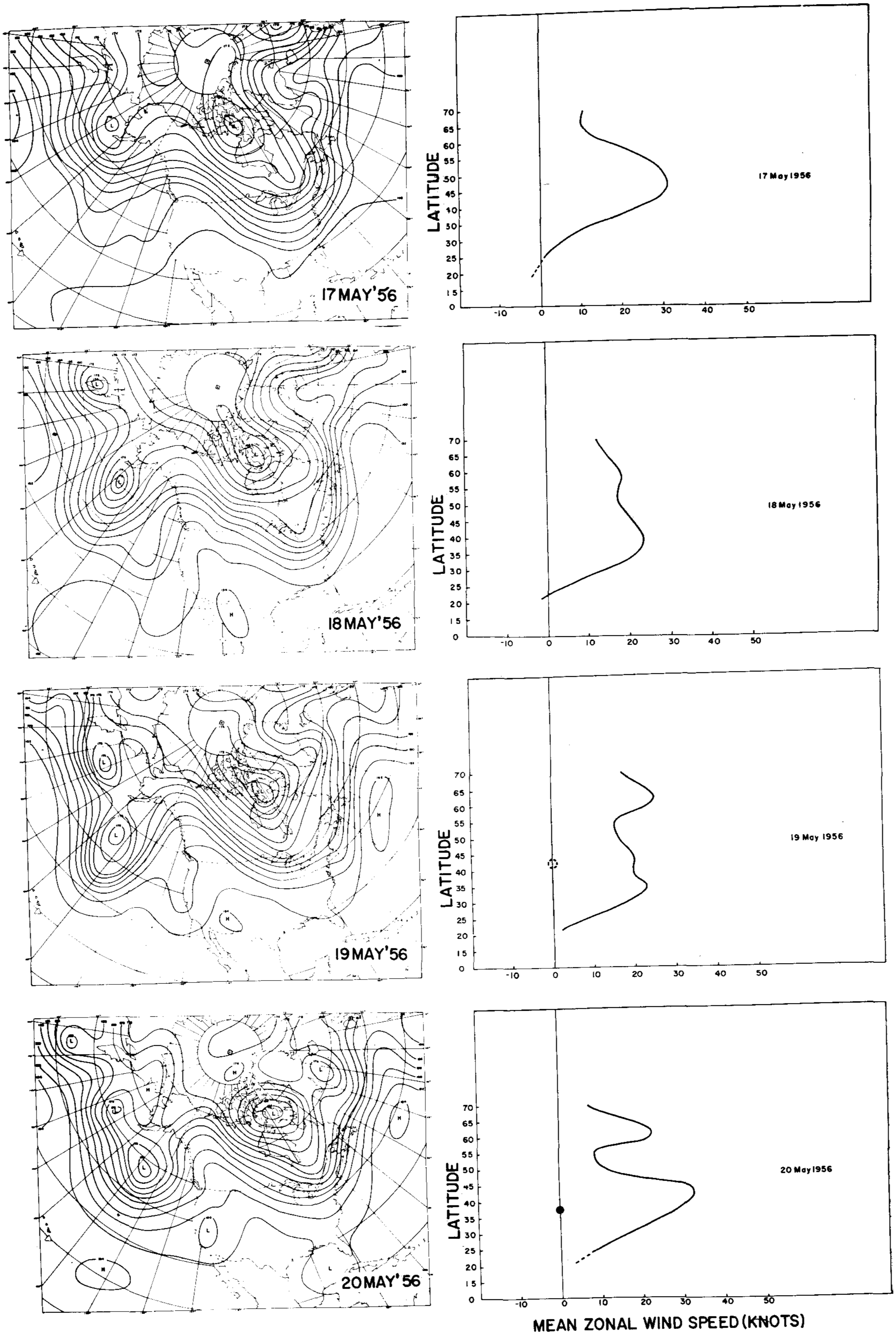

FIGURE 5.—Type IIIc (blocking) cyclone development at 500 mb., May 17–20, 1956.

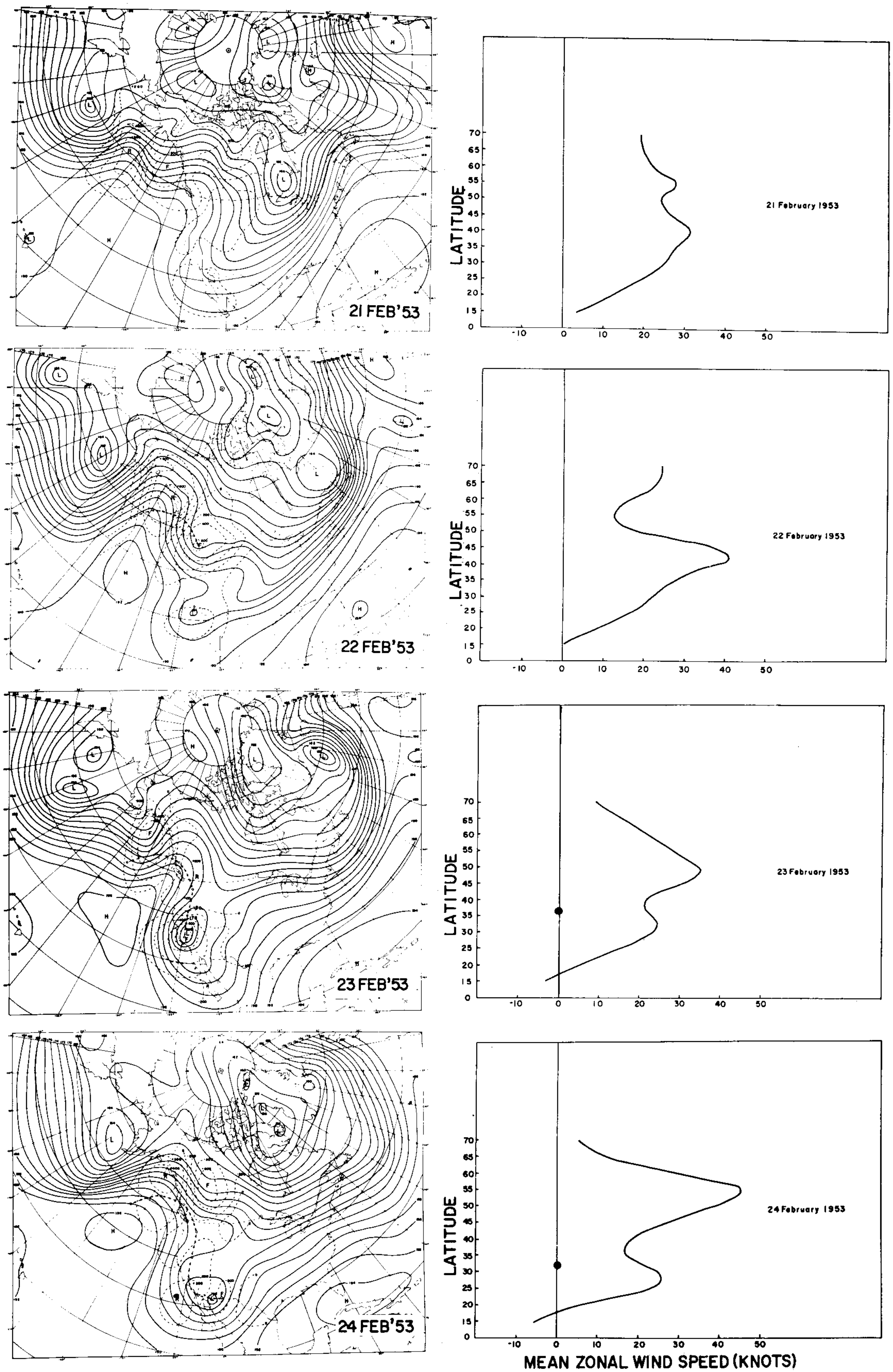

FIGURE 6.—Type IIId (pressure pulse) cyclone development at 500 mb., February 21–24, 1953. Dashed lines are 100-foot 12-hourly isallohypses. F denotes falling height, R rising height.

TABLE 1.—*Mean zonal (X) and meridional (Y) components of daily displacement of 500-mb. cyclones, according to type. Positive numbers denote displacements toward the east and north, negative numbers toward west and south. Units are degrees of latitude. S_x and S_y are the standard deviations. N is the number of cases.*

Cyclone Type	X	S_x	Y	S_y	N
I	4.0	6.0	−0.4	3.8	994
II	3.9	5.7	0.7	4.3	1108
III	1.4	4.6	1.0	3.6	850

ward. Subsequently the height-change center and the cyclone moved together toward the south. With the development of the Low, a secondary zonal velocity maximum appeared south of the cyclone.

3. MEAN DAILY DISPLACEMENTS OF THE CYCLONE TYPES

It is of some interest to determine if the cyclone types are distinguished by characteristics other than their locations relative to the maximum westerlies. Therefore a sample of 500-mb. cyclones was collected. The cyclones were classified into types I, II, or III, their 24-hour displacements were measured, and a statistical test was applied to determine if the differences among the mean displacements of the three types were statistically significant.

The sample included all 500-mb. cyclones in the region between latitudes 20° N. and 60° N. and longitudes 45° W. and 145° W. (the North American sector) which persisted for at least 24 hours during the period December 1, 1946 through November 30, 1952. Zonal and meridional components of the 24-hour displacements of the cyclones, expressed in units of degrees of latitude, were measured on the published daily 500-mb. maps for the period (Air Weather Service [4] and U. S. Weather Bureau [5]). A cyclone was defined as a height minimum enclosed by a 200-foot contour lying entirely within the sector described above. A total of 2952 daily displacements, rather evenly divided among types I, II, and III, were included in the sample. Since some of the centers persisted for more than one day, a single cyclone could contribute more than one displacement to the data.

The statistical results are shown in tables 1 and 2. Table 1 gives the mean daily zonal and meridional displacement components and their standard deviations for each cyclone type. Table 2 gives the "t" values for the differences between the displacements of the different cyclone types. The "t" values may be used to estimate the significance of these differences, if the displacements are normally distributed. (See, e. g., Brooks and Carruthers [6]).

TABLE 2.—*"t" values computed from data in table 1. (See e. g., Brooks and Carruthers [6].)*

Cyclone Types	X	Y
I–II	0.2	6.1
I–III	10.1	8.3
II–III	10.4	2.0

Note: "t" values in excess of 1.96, 2.58 and 3.29 are significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

The high-latitude type I and middle-latitude type II cyclones have almost identical mean zonal displacements, and the "t" value for the difference between the two is not statistically significant. However, the type II cyclones have a mean northward displacement, while type I Lows have a mean displacement toward the south. The "t" value for this difference in the meridional component is highly significant. (The probability that the difference is due to chance is less than 0.001.)

Type III cyclones exhibit a slower drift toward the east than either type I or II. The difference between the mean zonal displacement of type III cyclones and that of the other types is highly significant. The difference between the mean meridional displacement of type III cyclones and that of type II is just barely significant at the 5 percent level. On the other hand, type III and type I Lows differ very significantly in their mean meridional displacements, according to table 2.

It is apparent that statistically significant differences in the mean motion of all three cyclone types do exist.

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